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Is the prevalence of antibiotic-resistant organisms changing in Canadian hospitals? Comparison of point-prevalence survey results in 2010 and 2012

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Abstract

A national point-prevalence survey for infection or colonization with methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE), and for *Clostridium difficile* infection (CDI) was done in Canadian hospitals in 2010. A follow-up survey was done in November 2012 to determine whether there were any changes in the prevalence of these organisms; we also determined the prevalence of extended-spectrum β-lactamase (ESBL)-producing Enterobacteriaceae, and carbapenem-resistant Enterobacteriaceae (CREs). Associations between prevalence and infection prevention and control policies were evaluated in logistic regression models. A total of 143 (67% of eligible facilities) hospitals with 29 042 adult inpatients participated in the survey, with representation from all 10 provinces; 132 hospitals participated in 2010 and 2012. There were no significant changes in the median prevalence of MRSA in 2010 (4.3%) compared to 2012 (3.9%), or of CDI in 2010 (0.8%) compared to 2012 (0.9%). A higher median prevalence of VRE was identified in 2012 (1.3%) compared to 2010 (0.5%) (p 0.04), despite decreased VRE screening in 2012. The median prevalence of ESBLs was 0.7% and was 0 for CREs; CREs were reported from only 10 hospitals (7.0%). A policy of routinely caring for patients with MRSA or VRE in a private isolation room was associated with lower prevalence of these organisms. Targeted screening of high-risk patients at admission was associated with lower MRSA prevalence; better hand hygiene compliance was associated with lower VRE prevalence. These data provide national prevalence rates for antibiotic-resistant organisms among adults hospitalized in Canadian hospitals. Certain infection prevention and control policies were associated with prevalence.

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Introduction

Prospective national surveillance for antibiotic-resistant organisms (AROs) in Canada has been conducted by the Canadian Nosocomial Infection Surveillance Program since 1995 [1–4]. Although the surveillance provides important incidence data, it is limited in that only a relatively small number of hospitals, predominantly tertiary-care teaching facilities, participate. In 2010, we conducted the first national prevalence survey of AROs, including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), and *Clostridium difficile* infection (CDI), in a large and representative sample of Canadian hospitals [5]. However, as the epidemiology of these organisms continues to evolve, it is important to monitor changes that may occur over time. Therefore, we conducted a follow-up point-prevalence survey in Canadian hospitals in 2012, this time expanding the survey to also include information regarding extended-spectrum β-lactamase (ESBL)-producing organisms and carbapenem-resistant Enterobacteriaceae (CREs). We also

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determined institutional characteristics and infection prevention and control policies associated with the prevalence of AROs.

Materials and methods

Study design and study participants

The methods and study definitions used in this survey were similar to those described for the survey done in 2010 [5]. All acute-care hospitals in Canada with at least 50 inpatient beds for adults were invited to participate. Hospitals providing only pediatric, rehabilitation, psychiatric, or long-term care were excluded. Participating hospitals were asked to select one weekday between 5 November and 16 November 2012 on which to conduct the survey. On the survey date, all adult (≥18 years of age) inpatients were identified by the hospital census, and those colonized or infected with MRSA, VRE, ESBL or CRE, or who had CDI were determined using hospital infection prevention and control and laboratory databases. Medical records were reviewed to determine whether the patient met criteria for infection, and whether the ARO was healthcare or community associated. A standardized questionnaire describing hospital characteristics (size, type of facility, scope of medical services provided and laboratory facilities for ARO detection), and the facilities' infection prevention and control policies regarding AROs was completed. Infection control professionals at the participating hospitals received standardized webinar training for data collection. The Ethics Review Board at Sunnybrook Health Sciences Centre (Toronto, Ontario) approved the conduct of this study.

Study definitions

At the time of the survey, it was a standard practice in Canadian hospitals for patients colonized or infected with any one of the target AROs to be cared for with additional infection control precautions (contact isolation). Therefore, patients with MRSA, VRE, ESBL or CRE were defined as those who were on additional precautions for any of these organisms on the day of the survey and who had had a culture confirming the presence of the organism obtained on that day or any time previously. Patients were determined to have an infection caused by these organisms if they met National Healthcare Safety Network criteria [6]. CDI was diagnosed in the presence of diarrhea (three or more watery stools within 24 hours) with a positive *C. difficile* toxin assay, and receipt of treatment for this with either metronidazole or oral vancomycin on the day of the survey, or if pseudomembranous colitis had been documented by endoscopy within the previous 14 days [2]. MRSA, VRE and CDI were determined to be community or healthcare associated using standard criteria [1,2,5].

Data analysis and statistical methods

The primary outcomes were the prevalence of each of the AROs, calculated as the number of cases per 100 adult inpatients in each of the participating hospitals on the survey date. For each ARO, the median prevalence in 2010 and 2012 was compared by the Mann-Whitney *U* test. In order to describe institutional characteristics and policies associated with prevalence, multivariable logistic regression models were run using sets of variables that had been selected *a priori*. Before modelling, the set of variables were assessed for multicollinearity using tolerance statistics. If the tolerance statistic was less than 0.4, only one member of a correlated set of variables was retained for the multivariable model. Estimates from the model were displayed using odds ratios and their associated 95% confidence intervals. Two-tailed p values less than 0.05 were considered to be significant. All analyses were carried out by SAS version 9.3 (SAS Institute, Cary, NC, USA).

Results

A total of 143 hospitals (representing 67% of eligible facilities) with 30 609 acute-care beds (69% of eligible inpatient beds) participated in the survey and submitted data in 2012 (132 hospitals participated in both 2010 and 2012). There was participation from all 10 Canadian provinces, with 45 teaching hospitals (31%). There were 79 hospitals (55%) with fewer than 200 beds, and six (4%) with more than 500 beds. The geographic distribution, hospital size and proportion of teaching hospitals participating in 2012 did not differ from those participating in 2010 (Table 1) [5].

Participating hospitals reported a total of 2533 (8.7 per 100 inpatients; 95% confidence interval (CI), 8.4–9.1) patients with at least one of the targeted AROs: 1308 (4.5/100 inpatients; 95% CI, 4.3–4.8) colonized or infected with MRSA, 190 (0.7/

TABLE 1. Characteristics of participating Canadian hospitals in 2010 and 2012

Hospital characteristic	2010, *n* (%)	2012, *n* (%)
Region[a]		
Eastern Canada	26 (15)	24 (17)
Central Canada	103 (58)	88 (61)
Western Canada	47 (27)	31 (22)
Size		
≤200 beds	92 (52)	79 (55)
201–500 beds	74 (42)	58 (41)
>500 beds	10 (6)	6 (4)
Type		
Teaching	55 (31)	45 (31)
Nonteaching	121(69)	98 (69)

[a]Regions are as follows: Eastern Canada, Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick; Central Canada, Quebec and Ontario; and Western Canada, Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories.

100 inpatients; 95% CI, 0.6–0.8) with MRSA infection, 779 (2.7/100 inpatients; 95% CI, 2.5–2.9) colonized or infected with VRE, 410 (1.4/100 inpatients; 95% CI, 1.3–1.6) with CDI, 362 (1.3/100 inpatients; 95% CI, 1.1–1.4) colonized or infected with an ESBL-producing organism and 32 (0.1/100 inpatients; 95% CI, 0.08–0.16) colonized or infected with a CRE. Most (55%) of the carbapenemases identified were *Klebsiella pneumoniae* carbapenemase; others included OXA-48 (20%) and NDM-1 (15%). There were 292 patients (11.5%) concurrently infected or colonized with two or more of the AROs. MRSA, CDI and VRE were most often healthcare associated, and were thought to have been community-acquired in 29.9%, 22.7% and 5.6% of patients, respectively. Few patients were identified with VRE or CRE infections. Patients with MRSA were reported from almost all hospitals (93.7%); patients with VRE were reported in 97 hospitals (67.8%), CDI in 96 (67.1%), ESBLs in 71 (49.7%) and CRE in only 10 (7.0%). Although the prevalence of MRSA did not differ by region of the country, the prevalence of VRE colonization or infection was lower in eastern Canada compared to the rest of the country (median prevalence 0 per 100 inpatients vs. 1.9 and 1.3 in central and western Canada, respectively; p 0.001) (Fig. 1). The central region of Canada had a higher prevalence of CDI (1.4 per 100 inpatients vs. 0.4 in eastern and western Canada; $p < 0.001$).

The mean and median prevalence of the AROs reported in 2010 and 2012 from the 132 hospitals that participated in both surveys are summarized in Table 2. There were no significant changes in the prevalence of MRSA or CDI, but a higher prevalence of VRE colonization and infection was identified in 2012 (median 1.3 per 100 inpatients) compared to 2010 (0.5 per 100 inpatients; p 0.04).

In 2010 and 2012, all participating hospitals conducted either universal or targeted active surveillance for MRSA colonization and infection. However, screening for VRE colonization decreased from almost all hospitals (99.4%) in 2010 to 128 hospitals (89.5%) in 2012 ($p < 0.001$), and a minority of hospitals conducted active surveillance for ESBLs (32%) or CREs (32%). The proportion of hospitals using a PCR assay for detection of *C. difficile* toxin genes increased from 9% in 2010 to 48% in 2012. Institutional characteristics and hospital infection prevention and control policies associated with MRSA, VRE and CDI prevalence in 2012 are summarized in Table 3. Teaching hospitals had higher prevalence of CDI, whereas hospitals with solid organ transplant units had higher prevalence of VRE. Several infection control policies including ARO screening of high-risk patients, use of private isolation rooms, routine provision of MRSA decolonization, measures of hand hygiene compliance and enhanced environmental cleaning were found to be associated with prevalence.

Discussion

Despite ongoing concerns that antibiotic resistance is an increasing public health threat globally, the epidemiology and outcomes associated with AROs in healthcare settings remain

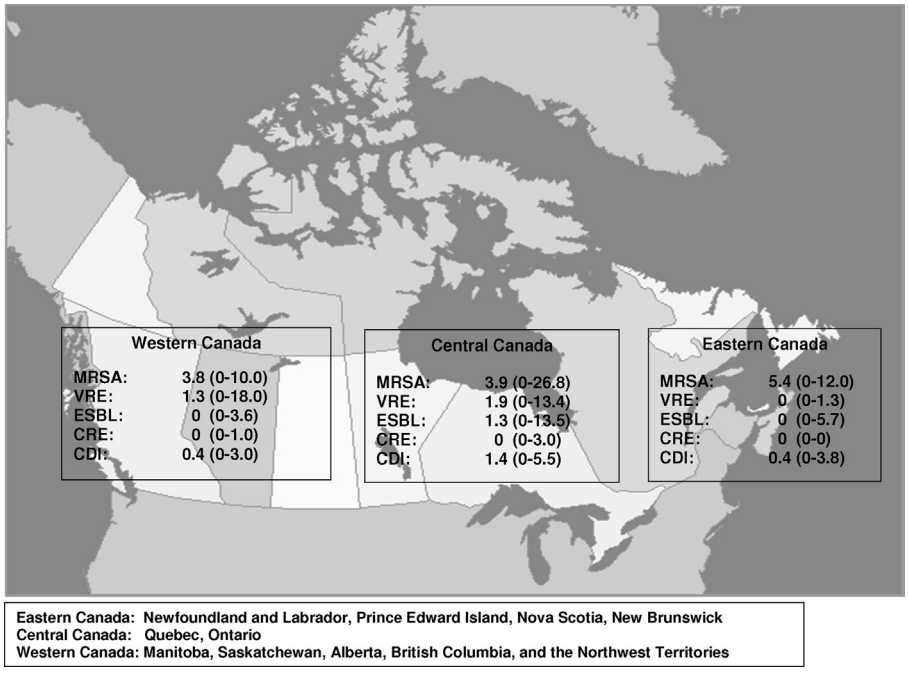

FIG. 1. Median (range) prevalence (per 100 inpatients) of methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), extended-spectrum β-lactamase (ESBL)-producing Enterobacteriaceae, carbapenem-resistant Enterobacteriaceae (CRE) and *Clostridium difficile* infection (CDI) in Canada, 2012.

TABLE 2. Mean and median prevalence of selected antimicrobial-resistant organisms in adult inpatients of Canadian acute-care hospitals, 2010 and 2012

	2010 Prevalence (per 100 inpatients)			2012 Prevalence (per 100 inpatients)			
Organism	***n***	**Mean (SD)**	**Median (range)**	***n***	**Mean (SD)**	**Median (range)**	**p[a]**
MRSA							
Colonization or infection	1472	5.1 (4.0)	4.3 (0–22.1)	1218	4.8 (3.8)	3.9 (0.-26.8)	0.81
Infection	175	0.6 (0.9)	0.3 (0–5.9)	170	0.7 (0.9)	0.3 (0–4.9)	0.78
VRE							
Colonization or infection	557	1.7 (2.7)	0.5 (0–13.0)	738	2.3 (3.2)	1.3 (0–18.0)	0.04
Infection	11	0.05 (0.2)	0 (0–1.8)	18	0.06 (0.2)	0 (0–1.5)	0.28
CDI	350	1.1 (1.2)	0.8 (0–8.6)	386	1.2 (1.2)	0.9 (0–5.5)	0.29
ESBL							
Colonization or infection		Not measured		345	1.4 (2.2)	0.7 (0–13.5)	
Infection		Not measured		97	0.4 (0.7)	0 (0–4.0)	
CRE							
Colonization or infection		Not measured		32	0.07 (0.3)	0 (0–3.0)	
Infection		Not measured		12	0.03 (0.2)	0 (0–1.3)	

CDI, *Clostridium difficile* infection; CRE, carbapenem-resistant Enterobacteriaceae; ESBL, extended-spectrum β-lactamase-producing Enterobacteriaceae; MRSA, methicillin-resistant *Staphylococcus aureus*; VRE, vancomycin-resistant *Enterococcus*.
[a]Comparing median prevalence in 2010 with that in 2012.

poorly understood, largely because few countries have robust or comprehensive surveillance programs in place (http://www.cdc.gov/drugresistance/threat-report-2013/pdf/ar-threats-2013-508.pdf; http://www.who.int/drugresistance/documents/surveillancereport/en/). National surveillance for AROs in Canada has been conducted by the Canadian Nosocomial Infection Surveillance Program, providing incidence data [1–4], but the number of participating hospitals is relatively small. Prevalence surveys can provide a snapshot of the burden of disease associated with AROs and may permit a larger and more representative sample of hospitals to participate. This point-prevalence survey determined that approximately one in 11 hospitalized adults in Canada was colonized or infected with one of the targeted AROs. With approximately 36 776 acute-care beds, and 93% bed occupancy rates in Canadian hospitals (http://www.oecd.org/health/healthdata), this would correspond to at least 2976 hospitalized patients with an ARO in Canada on any given day. This is an underestimate, as other significant resistant phenotypes were not included in the survey.

As observed in other parts of the world, the single most common ARO identified in the point-prevalence survey as causing infection in Canadian hospitals was *C. difficile* [7,8]. *C. difficile* has also been reported to be the most common bacterial pathogen associated with infection outbreaks in healthcare facilities [9]. Recently in Canada there has been a

TABLE 3. Covariates associated with infection prevalence in multivariate models

	MRSA colonization/infection		MRSA infection		VRE colonization/infection		CDI	
Covariates	**OR (95% CI)**	**p**	**OR (95% CI)**	**p**	**OR (95% CI)**	**p**	**OR (95% CI)**	**p**
Occupancy rate	1.00 (0.99–1.01)	0.90	1.01 (1.00–1.03)	0.08	0.99 (0.98–1.00)	0.02	1.01 (0.99–1.01)	0.19
Teaching hospital	0.99 (0.86–1.14)	0.91	0.82 (0.58–1.17)	0.27	1.13 (0.95–1.35)	0.16	1.26 (1.02–1.55)	0.03
Inpatient pediatrics	0.85 (0.74–0.98)	0.03	1.02 (0.71–1.45)	0.93				
Solid organ transplant unit					1.31 (1.06–1.63)	0.01		
Targeted admission screening[a]	0.75 (0.65–0.86)	<0.001	1.14 (0.80–1.63)	0.47	1.03 (0.87–1.23)	0.73		
ICU admission screening	1.01 (0.88–1.16)	0.85	0.93 (0.67–1.30)	0.68	1.75 (1.46–2.11)	<0.001		
Nasal + extranasal screening	1.34 (0.89–2.01)	0.16	3.52 (0.47–26.58)	0.22				
Routine use of private room	0.74 (0.64–0.86)	<0.001	0.42 (0.28–0.64)	<0.001	0.42 (0.36–0.50)	<0.001	0.86 (0.68–1.09)	0.22
Routine use of surgical mask	0.75 (0.61–0.92)	0.006	0.92 (0.55–1.56)	0.76				
Routine use of antiseptic soap[b]	1.13 (0.97–1.32)	0.13	1.38 (0.94–2.03)	0.10				
Routine MRSA decolonization[c]	0.59 (0.48–0.73)	<0.001	0.77 (0.44–1.35)	0.36				
Enhanced environmental cleaning	0.82 (0.72–0.93)	0.001	0.96 (0.70–1.31)	0.78	0.86 (0.67–1.10)	0.22		
Hand hygiene compliance >80%	0.92 (0.80–1.06)	0.26	0.92 (0.64–1.33)	0.66	0.72 (0.59–0.88)	0.002	1.12 (0.89–1.41)	0.35
>200 hand hygiene opportunities audited per unit per year	1.04 (0.91–1.18)	0.60	1.00 (0.71–1.42)	0.99	0.76 (0.64–0.89)	<0.001	1.21 (0.96–1.52)	0.10
Turnaround time <24 hours for receipt of *C. difficile* laboratory test results							1.42 (1.08–1.85)	0.01

Not all covariates were tested in all of the models; results presented for the covariates included in each model.
CDI *Clostridium difficile* infection; CI, confidence interval; ICU, intensive care unit; MRSA, methicillin-resistant *Staphylococcus aureus*; OR, odds ratio; VRE, vancomycin-resistant *Enterococcus*.
[a]Targeted screening for MRSA or VRE at admission to hospital on the basis of risk factor assessment.
[b]Daily bathing/washing of infected or colonized patient using antiseptic soap, such as chlorhexidine gluconate.
[c]MRSA decolonization, with intranasal mupirocin with or without use of other topical or systemic agents.

trend towards a decreasing incidence of CDI in hospitalized patients from 6.8/10 000 patient-days in 2007 to 6.0/10 000 patient-days in 2012 ($p < 0.001$) [10]. The CDI prevalence in our study did not change in 2012 compared to that found in 2010, and was similar (mean 1.2/100 inpatients) to that reported in national surveillance done in the United States (1.3/100 patients), the United Kingdom (1.7/100 inpatients), and Germany (1.3/100 patients) [11–13].

The prevalence of MRSA in Canadian hospitals did not substantially change between 2010 and 2012, and a relatively small proportion of patients (15%) had MRSA infection, representing a mean MRSA infection prevalence of 0.7/100 inpatients. Although the incidence of invasive healthcare-associated MRSA infections has been decreasing in the United States [14], the recently reported prevalence of MRSA infections in US hospitals (2.5 per 100 patients) [15] is higher than that observed in the current study. The prevalence of MRSA in European hospitals varies considerably, and has ranged from less than 1% (in the Netherlands) to 24% in certain patient populations in British hospitals [16–18]. Some of this variability is likely related to regional and national differences in the implementation of infection prevention and control interventions.

The proportion of *Enterococcus faecium* isolates resistant to glycopeptides varies considerably across Europe, but has increased recently in a few countries [17,19], and VRE are endemic in many US facilities [20]. We found that the prevalence of VRE-colonized patients has increased significantly in Canadian hospitals, despite the fact that in 2012 fewer hospitals were conducting active surveillance for this organism. These data suggest increasing VRE transmission in hospitals in Canada, but to date there has been no apparent increase in VRE infection rates, and the number of VRE infections identified in Canadian hospitals remains generally low [4].

This study is the first to provide national prevalence results for multi-drug-resistant Gram-negative organisms such as ESBLs and CREs in Canadian hospitals. Detection of ESBL colonization is dependent on screening protocols, which were routinely used in only one-third of Canadian hospitals. Therefore, the observed prevalence in this study is likely an underestimate. However, the ESBL infection rate (not subject to the same detection bias) appeared to be relatively low (mean 0.4 per 100 inpatients). There are few comparable data from other countries, but the mean ESBL colonization/infection prevalence in this study (1.4 per 100 inpatients) was similar to that recently reported in German hospitals (1.2%) [13]. Rising CRE rates have been recently reported from many countries [21–23]. In 2012, 4.6% of US hospitals reported at least one CRE-related healthcare-associated infection, and the proportion of Enterobacteriaceae that were carbapenem resistant increased from 1.2% in 2001 to 4.2% in 2011 [21]. In Europe, 20 countries reported one or more invasive *K. pneumoniae* isolate resistant to carbapenems in 2012, and these organisms appear to have become endemic in certain countries [22,23]. Carbapenemase-producing organisms were rarely identified in Canadian hospitals before 2010 [3]. Patients with CRE infection or colonization (predominantly *K. pneumoniae* carbapenemase, OXA-48 and NDM-1) were also infrequently identified in the current survey, and were reported from only 10 hospitals (7%).

A secondary objective of this study was to identify institutional characteristics or policies associated with prevalence of MRSA, VRE and CDI. As reported in our 2010 survey, a policy of routinely placing patients colonized or infected with MRSA or VRE into a private room was associated with a lower prevalence of these organisms [5]. Pre-emptive isolation of high-risk patients was associated with lower rates of MRSA bloodstream infections in Europe [24], but with high occupancy rates (generally >92%), this approach is not often feasible in Canadian hospitals. Targeted screening of high-risk patients at admission and MRSA decolonization were associated with lower MRSA prevalence, whereas more frequent hand hygiene audits and higher hand hygiene compliance were associated with lower VRE prevalence. In univariate analyses, hospitals with a greater number of full-time-equivalent infection control professionals per 100 inpatient beds had lower VRE prevalence (unadjusted odds ratio 0.58, 95% CI 0.50–0.67), but there was no such association with MRSA or CDI prevalence (Appendix 1, available online). As anticipated, hospitals that conducted periodic prevalence screening of inpatient units for MRSA or VRE had higher rates of these organisms. These variables were not included in the final logistic regression models. It is important to note that these results describe associations between certain infection prevention and control policies and prevalence of AROs, and do not necessarily imply a causal relationship. Moreover, we were unable to audit actual practice or policy implementation. However, these findings are consistent with those of others suggesting that implementation of certain infection control interventions may lead to lower prevalence of AROs [25–27].

We believe that the results of this study are representative of Canadian adult acute-care hospitals with at least 50 inpatient beds, as two-thirds of all eligible hospitals from all 10 provinces participated, with characteristics similar to those of nonparticipating facilities. Moreover, 75% of hospitals that responded to the 2010 survey also participated in 2012, allowing for an analysis of trends in prevalence over time. These results are not applicable to pediatric hospitals or to rehabilitation, psychiatric or long-term care facilities. Detection bias and sampling variation may have affected the identification of colonized patients as

screening practices varied, particularly for resistant Gram-negative organisms.

In summary, the prevalence of ARO infections in Canadian hospitals was relatively low, and remained stable between 2010 and 2012. However, the prevalence of VRE colonization increased between 2010 and 2012, despite a decrease in the use of active surveillance and of additional infection control precautions for patients with VRE. This study also provides the first national prevalence rates for ESBLs and CREs. Ongoing national surveillance for AROs is essential to monitor changes in the burden of disease associated with these organisms over time and to determine the effects of various interventions.

Appendix Table. Univariate analyses of hospital characteristics and infection prevention and control policies associated with the prevalence of antibiotic resistant organisms in Canadian hospitals

	MRSA Colonization/Infection		MRSA Infection		VRE Colonization /Infection		*Clostridium difficile* Infection	
Variable	**OR (95% CI)**	***p* value**	**OR (95% CI)**	***p* value**	**OR (95% CI)**	***p* value**	**OR (95% CI)**	***p* value**
Hospital size >200 beds	0.84 (0.74-0.95)	0.005	0.82 (0.60-1.12)	0.21	1.94 (1.60-2.35)	<0.001	1.67 (1.30-2.15)	<0.001
Occupancy rate	1.00 (0.99-1.01)	0.11	1.01 (0.99-1.02)	0.27	1.00 (0.99-1.01)	0.33	1.01 (1.00-1.02)	0.05
Teaching hospital	1.06 (0.95-1.87)	0.29	0.98 (0.74-1.31)	0.91	1.39 (1.20-1.60)	<0.001	1.27 (1.05-1.55)	0.02
No. FTE ICP/100 beds*	1.25 (1.14-1.37)	<0.001	1.24 (0.98-1.57)	0.07	0.58 (0.50-0.67)	<0.001	0.97 (0.81-1.16)	0.73
Hemodialysis	0.91 (0.80-1.03)	0.14	1.01 (0.73-1.41)	0.94	1.35 (1.13-1.62)	<0.001	1.24 (0.97-1.57)	0.08
Bone marrow transplant	1.17 (1.02-1.34)	0.03	1.48 (1.06-20.59)	0.02	1.19 (0.99-1.42)	0.06	1.17 (0.92-1.50)	0.09
Solid organ transplant	1.00 (0.87-1.17)	0.92	1.11 (0.76-1.62)	0.85	1.21 (1.01-1.46)	0.04	1.24 (0.97-1.60)	0.09
Pediatrics unit	0.72 (0.64-0.80)	<0.001	0.96 (0.72-1.29)	0.81	0.62 (0.53-0.71)	<0.001	0.80 (0.66-0.98)	0.03
Burn unit	1.01 (0.87-1.17)	0.88	1.16 (0.81-1.67)	0.43	0.61 (0.49-0.76)	<0.001	0.74 (0.56-0.99)	0.05
Cardiac surgery	1.14 (1.00-1.29)	0.05	1.01 (0.73-1.41)	0.94	1.55 (1.33-1.80)	<0.001	1.38 (1.12-1.70)	0.003
Neurosurgery	0.96 (0.85-1.09)	0.54	0.95 (0.70-1.30)	0.75	1.68 (1.45-1.94)	<0.001	1.14 (0.93-1.40)	0.22
Hand hygiene audits	0.82 (0.63-1.07)	0.14	1.94 (0.72-5.23)	0.19	1.07 (0.73-1.57)	0.73	1.62 (0.86-1.30)	0.14
Hand hygiene compliance > 80%	0.81 (0.72-0.91)	<0.001	0.82 (0.61-1.11)	0.20	1.18 (1.01-1.39)	0.04	0.77 (0.63-0.95)	0.001
Routine use of a private room	0.57 (0.51-0.64)	<0.001	0.39 (0.28-0.55)	<0.001	0.52 (0.45-0.61)	<0.001	0.98 (0.80-1.21)	0.89
Targeted vs universal admission screening	0.82 (0.73-0.92)	<0.001	1.21 (0.89-1.64)	0.22	0.96 (0.82-1.12)	0.61		
Periodic prevalence screening of inpatient units	1.16 (1.04-1.29)	0.01	0.82 (0.61-1.09)	0.17	1.16 (1.00-1.34)	0.05		
Enhanced environmental cleaning	0.78 (0.70-0.87)	<0.001	0.98 (0.73-1.30)	0.87	1.26 (1.05-1.52)	0.01		
Routine use of antiseptic soap for patient bathing/washing	1.03 (0.91-1.16)	0.67	1.10 (0.81-1.50)	0.53	0.72 (0.57-0.89)	0.003		
Routine use of a surgical mask (for MRSA)	0.61 (0.52-0.71)	<0.001	0.76 (0.52-1.10)	0.14				
Routine MRSA decolonization	0.58 (0.50-0.69)	<0.001	0.57 (0.37-0.88)	0.01				
PCR testing for *C. difficile*							1.41 (1.15-1.73)	0.001

*FTE ICP, full-time equivalent infection control professional.

Transparency declaration

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References

[1] Simor AE, Gilbert NL, Gravel D, Mulvey MR, Bryce E, Loeb M, et al. Methicillin-resistant *Staphylococcus aureus* colonization or infection in Canada: national surveillance and changing epidemiology, 1995–2007. Infect Control Hosp Epidemiol 2010;31:348–56.

[2] Gravel D, Miller M, Simor A, Taylor G, Gardam M, McGeer A, et al. Health care-associated *Clostridium difficile* infection in adults admitted to acute care hospitals in Canada: a Canadian Nosocomial Infection Surveillance Program study. Clin Infect Dis 2009;48:568–76.

[3] Mataseje LF, Bryce E, Roscoe D, Boyd DA, Embree J, Gravel D, et al. Carbapenem-resistant Gram-negative bacilli in Canada, 2009–10: results from the Canadian nosocomial infection surveillance program (CNISP). J Antimicrob Chemother 2012;67:1359–67.

[4] McCracken M, Wong A, Mitchell R, Gravel D, Conly J, Embil J, et al. Molecular epidemiology of vancomcyin-resistant enterococcal bacteraemia: results from the Canadian Nosocomial Infection Surveillance Program, 1999–2009. J Antimicrob Chemother 2013;68:1505–9.

[5] Simor AE, Williams V, McGeer A, Raboud J, Larios O, Weiss K, et al. Prevalence of colonization and infection with methicillin-resistant

Staphylococcus aureus and vancomycin-resistant *Enterococcus* and of *Clostridium difficile* infection in Canadian hospitals. Infect Control Hosp Epidemiol 2013;34:687–93.

[6] Horan TC, Andrus M, Dudeck MA. CDC/NHSN surveillance definition of health care–associated infection and criteria for specific types of infections in the acute care setting. Am J Infect Control 2008;36:309–32.

[7] Miller BA, Chen LF, Sexton DJ, Anderson DJ. Comparison of the burdens of hospital-onset, healthcare facility-associated *Clostridium difficile* infection and of healthcare-associated infection due to methicillin-resistant *Staphylococcus aureus* in community hospitals. Infect Control Hosp Epidemiol 2011;32:387–90.

[8] Magill SS, Edwards JR, Bamberg W, Beldavs ZG, Dumyati G, Kainer MA, et al. Multistate point-prevalence survey of healthcare-associated infections. N Engl J Med 2014;370:1198–208.

[9] Haller S, Eckmanns T, Benzler J, Tolksdorf K, Claus H, Gilsdorf A, et al. Results from the first 12 months of the national surveillance of healthcare-associated outbreaks in Germany, 2011/2012. PLoS One 2014;9:e98100.

[10] Public Health Agency of Canada. Healthcare-associated *Clostridium difficile* infections in Canadian acute-care hospitals—surveillance report, January 1st, 2007 to December 31st, 2012. Ottawa: Centre for Communicable Diseases and Infection Control, Public Health Agency of Canada; 2014.

[11] Jarvis WR, Schlosser J, Jarvis AA, Chinn RY. National point-prevalence of *Clostridium difficile* in US health care facility inpatients, 2008. Am J Infect Control 2009;37:263–70.

[12] Health Protection Agency. Annual counts and rates of *C. difficile*. London: Health Protection Agency; 2007.

[13] Wegner C, Hübner NO, Gleich S, Thalmaier U, Krüger CM, Kramer A. One-day point prevalence of emerging bacterial pathogens in a nationwide sample of 62 German hospitals in 2012 and comparison with the results of the one-day point prevalence of 2010. GMS Hyg Infect Control 2013;8(1). Doc12, http://dx.doi.org/10.3205/dgkh00212.eCollection2013.

[14] Dantes R, Mu Y, Belflower R, Aragon D, Dumyati G, Harrison LH, et al. National burden of invasive methicillin-resistant *Staphylococcus aureus* infections, United States, 2011. JAMA Intern Med 2013;17:1970–8.

[15] Jarvis WR, Jarvis AA, Chinn RY. National prevalence of methicillin-resistant *Staphylococcus aureus* in inpatients at United States health care facilities, 2010. Am J Infect Control 2012;40:194–200.

[16] Dulon M, Haamann F, Peters C, Schablon A, Nienhaus A. MRSA prevalence in European healthcare settings: a review. BMC Infect Dis 2011;11:138.

[17] European Centre for Disease Prevention and Control Antimicrobial resistance surveillance in Europe, 2012. Annual report of the european antimicrobial resistance surveillance network (EARS-Net). Stockholm: ECDC; 2013.

[18] Köck R, Becker K, Cookson B, van Gemert-Pijnen JE, Harbarth S, Kluytmans J, et al. Methicillin-resistant *Staphylococcus aureus* (MRSA): burden of disease and control challenges in Europe. Euro Surveill 2010:15. pii=19688.

[19] Gastmeier P, Schröder C, Behnke M, Meyer E, Geffers C. Dramatic increase in vancomycin-resistant enterococci in Germany. J Antimicrob Chemother 2014;69:1660–4.

[20] Ramsey AM, Zilberberg MD. Secular trends of hospitalization with vancomycin-resistant *Enterococcus* infection in the United States, 2000–2006. Infect Control Hosp Epidemiol 2009;30:184–6.

[21] Jacob JT, Klein E, Laxminarayan R, Beldavs Z, Lynfeld R, Kallen AJ, et al. Vital signs: carbapenem-resistant Enterobacteriaceae. MMWR Morb Mortal Wkly Rep 2013;62:165–70.

[22] Magiorakos AP, Suetens C, Monnet DL, Gagliotti C, Heuer OE, EARS-Net Coordination Group, et al. The rise of carbapenem resistance in Europe: just the tip of the iceberg? Antimicrob Resist Infect Control 2013;2:6.

[23] Nordmann P, Poirel L. The difficult-to-treat spread of carbapenemase producers among Enterobacteriaceae worldwide. Clin Microbiol Infect 2014;20:821–30.

[24] Borg MA, Hulscher M, Scicluna EA, Richards J, Azanowsky JM, Xuereb D, et al. Prevention of methicillin-resistant *Staphylococcus aureus* bloodstream infections in European hospitals: moving beyond policies. J Hosp Infect 2014;87:203–11.

[25] Cooper BS, Stone SP, Kibbler CC, Cookson BD, Roberts JA, Medley GF, et al. Isolation measures in the hospital management of methicillin-resistant *Staphylococcus aureus* (MRSA): systematic review of the literature. BMJ 2004;329:533–7.

[26] MacKenzie FM, Bruce J, Struelens MJ, Goossens H, Mollison J, Gould IM. Antimicrobial drug use and infection control practices associated with the prevalence of methicillin-resistant *Staphylococcus aureus* in European hospitals. Clin Microbiol Infect 2007;13:269–76.

[27] Grammatico-Gaillon L, Thiolet JM, Bernillon P, Coignard B, Khoshnood B, Desenclos JC. Relationship between the prevalence of methicillin-resistant *Staphylococcus aureus* infection and indicators of nosocomial infection control measures: a population-based study in French hospitals. Infect Control Hosp Epidemiol 2009;30:861–9.